ESTUARY LESSON PLAN

# Eyes on the Estuaries

## Focus

Monitoring Living Resources in Estuaries

## Grade Level

9-12

## Focus Question

How can we monitor and compare living resources in U.S. estuaries?

## Learning Objectives

- Students will retrieve and interpret data on the distribution of selected estuarine animals at various stages in the life history of these animals and relate these distributions to salinity conditions.

- Students will compare the distribution of selected species in two or more estuaries, and to draw inferences about the ecology of these estuaries.

## Materials Needed

- copies of "ELMR Database Worksheet," one copy for each student group
- (optional) Computers with internet access; if students do not have access to the internet, download copies of materials cited under "Learning Procedure" and provide copies of these materials to each student or student group
- a spreadsheet program such as Microsoft Excel®

## Audio/Visual Materials Needed

None

## Teaching Time

One or two 45-minute class periods, plus time for student research

## Seating Arrangement

Groups of 3 - 4 students

## Maximum Number of Students

30

## Key Words

Estuary

## Background Information

Coastal ecosystems provide many benefits to human communities, including food, ports, recreational opportunities, habitats for diverse plant and animal life, and minerals. More than half of the U.S. population lives near a coast, and about one of every six jobs in the U.S. is related to coastal or marine resources. Because these systems are vulnerable to stress from natural processes and human activity, the National Ocean Service (NOS) has a variety of programs designed to protect coastal resources and the opportunities they provide. Two of the basic requirements for providing this protection are:

- The ability to recognize change in coastal resources; and
- The ability to distinguish normal variations from changes that may signal significant problems.

Coastal monitoring programs provide the information needed to recognize and interpret changes in coastal resources.

"Coastal monitoring" refers to periodic measurements of physical, chemical, biological, and meteorological factors that may affect the use and quality of coastal resources. For example, such factors may include temperature, salinity, presence of chemical contaminants, biological species, life stages of these species (eggs, juveniles, adults, etc.), rainfall, and storm events. NOS supports 28 different monitoring systems to provide key pieces of information needed to protect marine resources and control the ways in which they are used. These programs fall into four classes that represent different geographic scales.

The first class includes measurements of environmental features over large geographic areas using sensors or instruments on airplanes, satellites, and ships. These features include distribution of habitat types or land cover, algal blooms, water

depth, shoreline location, and land topography.
The second class includes physical, chemical, biological, and meteorological measurements at specific sites. These measurements are made periodically and are usually intended to provide information on specific resources or environmental stresses. Measurements include currents, water quality and weather in 26 National Estuarine Research Reserves, contaminants in sediments and bivalve molluscs at 250 sites, and water level measurements used to predict tides.

The third class includes intensive and frequent measurements of environmental conditions at a few locations of particular importance. These include coral reef ecosystems, 13 National Marine Sanctuaries, sites where there is a high potential for substantial environmental degradation (Narragansett Bay, Chesapeake Bay, and San Francisco Bay are among more than 280 sites being monitored) and real-time measurements of water levels, currents, and other oceanographic conditions in 10 U.S. ports including New York/New Jersey Harbor, Houston/Galveston Bay, Los Angeles/Long Beach, and the Port of Anchorage.

The fourth class includes monitoring activities that are focussed on a single physical location, ecosystem, or oil spill sites. The Everglades, Chesapeake Bay, and the M/V Selendang Ayu oil spill site in Alaska are among the areas included in this part of the NOS monitoring program.

This activity focuses on information contained in the NOS Estuarine Living Marine Resources (ELMR) Database. The ELMR Program was established to develop baseline information on ecologically and economically important fishes and invertebrates in U.S. estuaries. The database includes information on the distribution, relative abundance, and life history characteristics of 153 species found in 122 estuaries and coastal embayments on the Pacific, Atlantic, and Gulf of Mexico coasts. In this lesson, students will use the ELMR Database to compare characteristics of selected species in two or more estuaries, and to draw inferences about the ecology of these estuaries.

## Learning Procedure

1.

Decide which estuaries and which species within these estuaries will be assigned to each student group. If the same estuaries and species are assigned to each group, it will be easier for students to compare their results with those of other groups. On the other hand, assigning each group a different set of estuaries and species will provide greater variety, as well as ensure that each group does their own work; but this will also require more advance preparation by the teacher.

The key consideration is that the assigned species must be present in both assigned estuaries to permit comparison between the two sites. If the assigned estuaries are from different regions (Mid-Atlantic, South Atlantic, etc.) there is greater likelihood that there will be noticeable differences in the ecological characteristics of at least some of the species found in both locations. The best way to make these decisions is to visit the ELMR Database at *http://biogeo.nos.noaa.gov/products/data/elmr*, and scan through the data for estuaries that you think may be suitable to get an idea of the species for which data are available. You may want to include one or two invertebrate species as well as fishes for each student group. For example, the following species are among those that could be compared in the Winyah Bay and Chesapeake Bay estuaries:

Alewife
American Eel
American Shad
Atlantic Croaker
Atlantic Menhaden
Atlantic Sturgeon
Bay Anchovy
Black Drum
Blue Crab
Brown Shrimp
Daggerblade Grass Shrimp
Eastern Oyster
Pinfish
Quahog
Red Drum
Spot

Summer Flounder
Weakfish

2.
Discuss the importance of living estuarine resources and some of the sources of stress that may threaten these resources. Students should realize that stress may result from natural processes (such as storms, drought, or disease) as well as human activity such as coastal development, heavy industry, or oil spills. Be sure students understand that many organisms are adapted to withstand natural stresses, but may not be able to tolerate these stresses if they are also exposed to stress from human activities. Discuss the importance of being able to recognize change in populations of estuarine organisms and of being able to separate normal variability from unusual change. Both of these capabilities depend upon having "baseline" information about species of interest that can be compared with new information from periodic monitoring of these species.

Tell students that their assignment is to prepare a written report in which they summarize baseline information about selected species in two (or more) estuaries, and use this information to draw inferences about the ecology of these species. Be sure students understand that the primary purpose of the ELMR Database is to provide a reference point for each estuary that can be used to analyze future monitoring data from the SAME estuary. These reference data, though, can also provide information about variations in the life history of individual species in different estuaries.

3.
Assign each student group at least three species in at least two different estuaries, and provide each group with a copy of the "ELMR Database Worksheet."

4.
Have each student group present an oral summary of their analyses and inferences based on steps 7 and 8 on the Worksheet. Students should understand that a defining characteristic of all estuaries is variable salinity, and that this characteristic can offer advantages to species that can tolerate a range of salinities. At a minimum, student analyses should accurate-

ly summarize abundance data for each of the five life stages, as well as the salinity ranges in which these stages were found. Inferences should include ideas about how these data may reflect reproductive strategies.

In a discussion of the Winyah Bay alewife data, for example, students should recognize that this species spawns throughout the spring, so eggs and spawning adults are most common during March, April, and May. As the eggs develop, larvae appear and are abundant through June. Juveniles appear somewhat later and remain abundant through November. Students may infer that eggs and larvae do not tolerate salinities above 0.5 ppt, or may hypothesize that these life stages inhabit low-salinity waters to avoid predators that require higher salinities. The latter hypothesis is supported by the observation that spawning adults were found only in waters with salinity of 0 - 0.5 ppt, even though non-spawning adults were equally abundant in all three salinity ranges. In addition, juveniles appear to expand their salinity range as they grow older. The absence of any life stages during December through February may suggest that alewife use estuaries primarily as spawning and nursery areas, and live in farther from shore during the winter months.

Severe storms or prolonged droughts may alter the salinity distribution within an estuary. Reductions in freshwater flow caused by droughts or seawater driven into estuaries by storm winds could both cause higher-than-normal salinities. This could be fatal for life stages of species that are confined to low salinity waters (such as the eggs, larvae, and young juveniles of alewife).

These patterns will vary, depending upon the estuary and species. White shrimp adults and juveniles, for example, are found in the Winyah Bay estuary throughout the year, though larvae of this species are only present from May through September. No eggs or spawning adults of this species were observed in any month, which might mean that spawning occurs elsewhere or more likely that these stages were missed by the sampling program that produced the data.

## The Bridge Connection

*http://www.vims.edu/bridge/* – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Habitats," then "Estuary" for links to resources about estuaries.

## The Me Connection

Have students write a brief essay describing a monitoring program for an ecosystem in their own community that is personally important. Essays should include an explanation of why this system is important (reasons could include ecological, economic, or aesthetic values, or a combination of these), what factors would be monitored, and how frequently monitoring should be done.

## Extensions

Visit *http://www.epa.gov/owow/estuaries/monitor/* for an online manual for Volunteer Estuary Monitoring, as well as information on the ecology of estuaries and how they are threatened.

## Resources

*http://www.epa.gov/owow/estuaries/kids/* – Games and activities about estuaries produced through the National Estuary Program

*http://www.onr.navy.mil/focus/ocean/* – Oceanography site from the Office of Naval Research including online quizzes and activities. See the "Habitats" section for information and activities about estuaries.

*http://www.ncnerr.org/education/estnet/index.html* – "Estuary-Net Project;" an online project for grades 9-12 to help solve non-point source pollution problems in estuaries and their watersheds

## National Science Education Standards

**Content Standard A: Science as Inquiry**

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

**Content Standard C: Life Science**

- Interdependence of organisms
- Behavior of organisms

**Content Standard E: Science and Technology**

- Abilities of technological design
- Understandings about science and technology

**Content Standard F: Science in Personal and Social Perspectives**

- Personal and community health
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

ESTUARY REVIEW

# ELMR Database Worksheet

The Estuarine Living Marine Resources (ELMR) Data Base includes data on selected fish and invertebrate species in 122 estuaries along the coastlines of the United States. Each estuary is divided into one of five salinity zones. In each zone, data are provided for the relative abundance of five life stages for each of the selected species that are present. These life stages are adults, eggs, juveniles, larvae, and spawning adults. Data for each life stage for each species are provided for each of twelve months. Relative abundance is represented by a scale from 0 to 5:

0 = not present
2 = rare
3 = common
4 = abundant
5 = highly abundant

An entry of "." means that no data are available.

Your assignment is to compare data for certain species in two or more estuaries assigned by your teacher. For each assigned species, you should find out:

- In what months is each of the five life stages present, and in what months is each stage most abundant?
- In what salinity range is each of the five life stages found during the months that it is most abundant?

The easiest way to make these comparisons is to download the necessary data, and import these data into a spreadsheet program that will allow you to sort, summarize, and graph them. Here's how to retrieve ELMR data and import them into Microsoft Excel® using the Winyah Bay estuary as an example:

1. Open the ELMR Database at *http://biogeo.nos.noaa.gov/products/data/elmr/*.

2. Select the "Region" that includes the estuary you are interested in (SOUTHEAST), then the appropriate estuary name in the "Estuary" window (WINYAH BAY). You can confine

your search to specific Species, Life Stages, and Salinity Zones, or just leave "ALL" selected in these windows. For now, leave "ALL" selected. Click the "Search" button.

3. Click the "Tab Delimited" button, then "Download Format" button. Give the file a name, then save it onto your hard drive.

4. Open the downloaded data file in Microsoft Excel®. You will get the Text Import Wizard.
   Step 1. Select "Delimited," "Start Import at Row: 1," and the operating system you are using next to "File Origin." Click "Next."

   Step 2. Select "Delimiters: Tab" and "Text Qualifier: ". " Click "Next."

   Step 3. Click the "General" button under "Column Data Format." Click "Finish."

5. You now have a spreadsheet with all of the data for Winyah Bay. Now you need to make a few adjustments to this spreadsheet to make it easier to analyze:
   a. Highlight rows 1 through 7, which contain information about the data file. Click "Delete" under the "Edit" menu.
   b. Highlight columns B and C. Under the "Format" menu, select "Column" and then "Width." Change the width of columns B and C to 20.
   c. Highlight columns E through P. Under the "Format" menu, select "Column" and then "Width." Change the width of columns E through P to 5.
   e. Highlight all cells by clicking on the empty cell in the upper left corner. Under the "Data" menu click "Sort." Check the box next to "Header Row" under "My list has." Under "Sort By" select "Common Name." Under "Then by" select "LifeStage." Click "OK."

6. Prepare data summary graphs for each of your assigned species as follows:
   a. Highlight all cells in columns C through P for all Life Stages of the species you are analyzing. For this example, suppose "Alewife" is one of your assigned species; then

you would highlight cells C2 through P16.

b. Click on the Chart Wizard icon. Select "Column" under "Chart type" and the upper left icon under "Chart sub-type." Click "Next."

c. Click the button next to "Rows" under "Series in." Click the "Series" tab, and remove all life stages except "Adults" and "Spawning." Click "Next." Click "Next."

d. Click the "Titles" tab. Enter a title for your chart (such as "Alewife Adults and Spawning"). Enter "Month" in the "Category (X) axis:" box and "Abundance" in the "Value (Y) axis:" box. Click "Next."

e. Click the button next to "As new sheet" and enter the name that you want to appear on the tab for your chart in the spreadsheet workspace. Click "Finish." You now have a column chart that shows the relative abundance of alewife adults and spawning adults in each salinity zone for each month.

f. If you want to print your chart and do not have a color printer, you may want to change the column fills to black and white patterns. To do this, double click on one of the columns on your chart. The "Format Data Series" dialogue box will open. Click on the "Patterns" tab, then the "Fill Effects" button under "Area." Click the "Pattern" tab. Select black in the window under "Foreground:" and white in the window under "Background:" Windows containing the various pattern options should appear under "Pattern:" Select the pattern you want, be sure it looks OK in the "Sample" box, then click "OK." Click "OK" in the "Format Data Series" dialogue box. The column on your chart should now contain a black-and-white fill pattern. Repeat these steps for the other columns.

g. Repeat steps a. and b. Click the button next to "Rows" under "Series in." Click the "Series" tab, and remove "Adults" and "Spawning" life stages. Click "Next," and repeat steps d. and e. You now have a second column chart that shows the relative abundance of alewife eggs, larvae, and juveniles in each salinity zone for each month. Adjust the column fills if necessary.

7. Use your chart to discover:

a. When are spawning adults most abundant?

b. When are eggs most abundant?

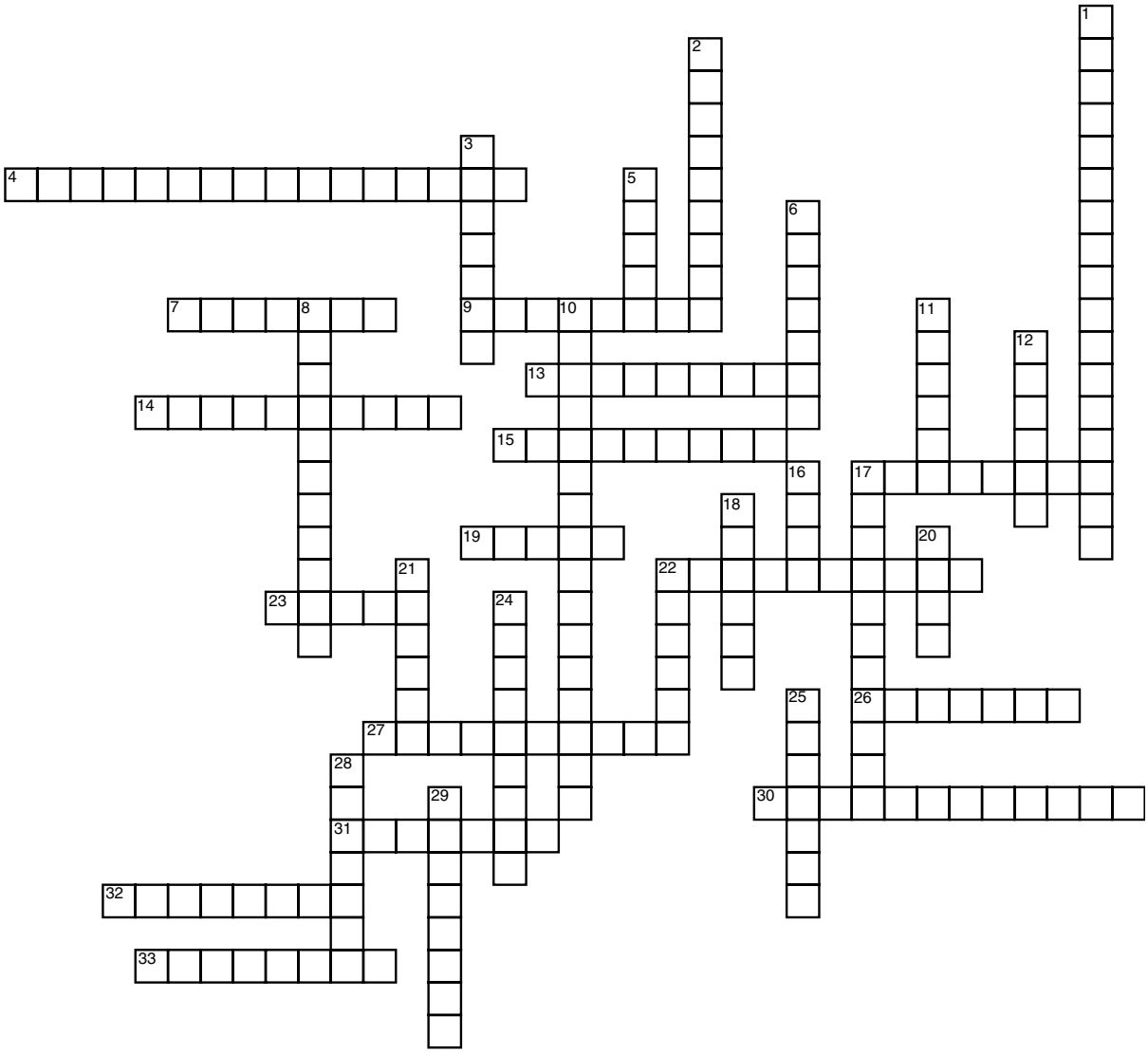
c. When are larvae most abundant?
d. When are juveniles most abundant?
e. When are adults most abundant?
f. Are any of these life stages more abundant in certain salinity zones?

For the Winyah Bay alewife example, adults and spawning adults are most abundant in March, April and May; eggs are most abundant in March, April and May; larvae are most abundant in March, April, May and June; juveniles are abundant from April through November. Notice that all life stages of alewife are absent from December through February. Different life stages of alewife appear to have different salinity preferences. Alewife eggs and larvae are found only in salinities of 0 - 0.5 ppt. Juveniles are also confined to this salinity zone during April, May, June, and July; but are found in the 0.5 - 25 ppt salinity zone between August and November, and in the >25 ppt zone between September and November. Alewife adults are found in all three salinity zones, but spawning adults are only found in the 0 - 0.5 ppt zone.

8. Discuss possible reasons for seasonal variations in the abundance of different life stages. What effect could severe storms or prolonged drought have on your assigned species?

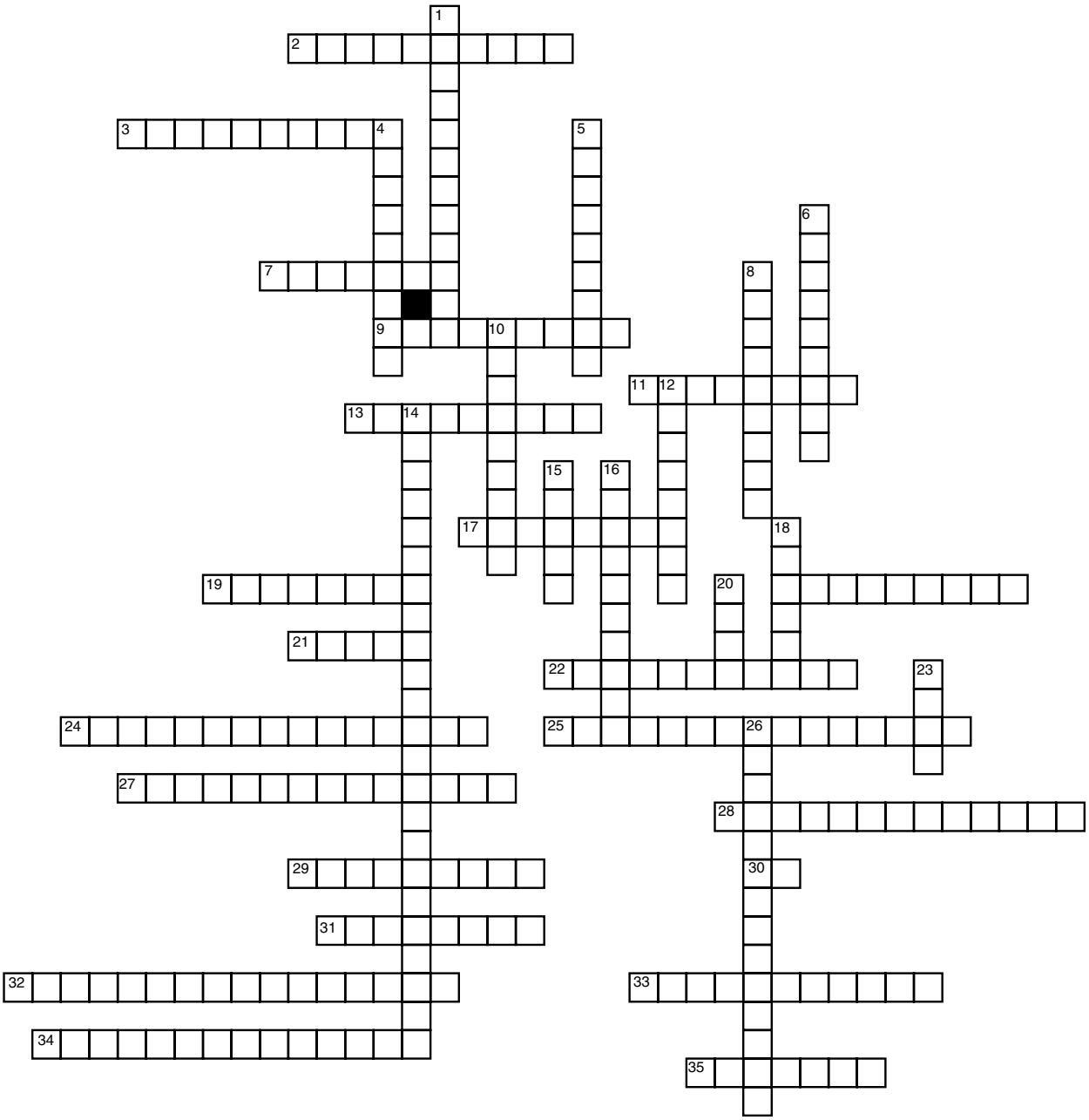
ESTUARY SELF TEST

# Crossword Puzzle No. 1



ESTUARY SELF TEST

# Crossword Puzzle No. 2



**Crossword Puzzle 1:**

**Across**

4. A _____ estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]
7. Estuaries and their surrounding wetlands act as _____ that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
9. Estuaries with a sill are found in areas that were once covered with _____.
13. _____ estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
14. Estuaries filter out _____ from rivers and streams before they flow into the oceans
15. One reason that estuaries are so productive is that the water filtering through them brings in _____ from the surrounding watershed.
17. _____ estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
19. _____ are a major influence on many estuaries.
22. Estuaries formed by rivers or streams entering massive lakes are called _____ estuaries.
23. A _____ is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
26. An _____ is a partially enclosed body of water and its adjancent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
27. _____ are areas in water that have equal salt concentrations.
30. _____ estuaries are formed when rising sea levels flood existing river valleys. [two words]
31. _____ beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
32. _____ estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
33. In the ocean the concentration of salts, or _____, averages about 35 parts per thousand

**Down**

1. _____ are fundamental life support processes upon which all organisms depend. [two words]

2. Estuaries are often called _____ of the sea.
3. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their _____.
5. Because freshwater flowing into the estuary is less _____ than water from the ocean, it often floats on top of the heavier seawater.
6. Tides at broad mudflats might appear to be _____ than tides at the end of a long, narrow inlet.
8. The first stage in the formation of a tectonic estuary typically occurs during _____.
10. The _____ determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
11. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes _____ (low oxygen) water to build up on the bottom of the estuary.
12. The shape of the isohalines indicates the amount of _____ that is occurring, and may provide clues about the estuary's geology.
16. Estuaries provide habitat for more than 75 percent of the _____ harvested in the United States.
17. Salt marshes are a mosaic of snaking channels called _____. [two words]
18. Most coastal plain estuaries in North America were formed at the end of the last _____. [two words]
20. _____ is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
21. Salt _____ are shallow depressions that contain very high concentrations of salt.
22. _____ are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
24. Of the 32 largest cities in the world, 22 are located on _____.
25. A protected area of calm water between the coast and a barrier island is called a _____.
28. Estuaries provide critical _____ for many birds, fish, amphibians, insects, and other wildlife.
29. Waters whose salt content is between that of freshwater and that of seawater are called _____.

**Crossword Puzzle 2:**

**Across**

2. Plants and animals that can tolerate a wide range of salinities are called _____.
3. Salt marshes are covered with salt-tolerant plants called _____.
7. In estuaries, salinity levels are generally _____ near the mouth of a river where the ocean water enters.
9. _____ is related to the amount of sediment and other solids suspended in water.
11. During low tides, oysters close up their shells, stop feeding, and switch to _____ respiration.
13. As water temperature increases, the amount of oxygen that can dissolve in the water _____.
17. As they develop, blue crabs eventually return to the estuary as young crabs called _____.
19. _____ trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
20. Plants and animals that can tolerate only slight changes in salinity are called _____.
21. _____ is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
22. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring _____.
24. _____ is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
25. The amount of _____ in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
27. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and _____.
28. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down _____. [two words]
29. The amount of oxygen that can dissolve in water _____ as salinity decreases.
30. The chemical components in seawater resist large changes to _____.
31. Burrowing organisms such as clams, mussels, oysters, fiddler

crabs, sand shrimp, and blood worms are typical of _____.

32. _____ is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
33. The _____ colonizes the seaward side of mangals. [two words]
34. Many species of mangrove trees have aerial roots called _____ that take up oxygen from the air for the roots.
35. The zone where white mangrove and buttonwood trees grow is almost never _____.

## Down

1. Non-native species are often introduced to estuaries in the _____ of ships. [two words]
4. Some toxic substances become attached to _____ that flow down rivers and get deposited in estuaries.
5. Many mangals can be recognized by their dense tangle of _____ that make the trees appear to be standing on stilts above the water. [two words]
6. A common natural disturbance to estuaries in non-tropical regions is _____. [two words]
8. _____ are disease-causing organisms.
10. _____ are plants and animals that have found their way into areas outside their normal range.
12. _____ pollution is the single largest pollution problem effecting coastal waters of the United States.
14. In most estuaries, the largest contributor of bacteria and viruses is probably _____. [three words]
15. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called _____.
16. Mangrove seeds that begin growing while still attached to the parent plant are called _____.
18. It requires a lot of _____ to adapt to constantly changing salinities.
20. The health of every National Estuary Reserve is continuously monitored by the _____.
23. Blue crab larvae called _____ require water with a salinity over 30 ppt for optimal development.
26. _____ is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

ESTUARY SELF TEST

# Fill-in-the-Blank

1. An _____ is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.

2. Waters whose salt content is between that of freshwater and that of seawater are called _____.

3. Of the 32 largest cities in the world, 22 are located on _____.

4. In the ocean the concentration of salts, or _____, averages about 35 parts per thousand.

5. The salinity of estuarine water is _____ from one day to the next.

6. _____ are a major influence on many estuaries.

7. Most areas of the earth experience _____ high and low tides each day.

8. Tides at broad mudflats might appear to be _____ than tides at the end of a long, narrow inlet.

9. Every estuary is _____.

10. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their _____.

11. Estuaries formed by rivers or streams entering massive lakes are called _____ estuaries.

12. Estuaries are often called _____ of the sea.

13. Estuaries filter out _____ from rivers and streams before they flow into the oceans.

14. Estuaries provide critical _____ for many birds, fish, amphibians, insects, and other wildlife.

15. Estuaries provide habitat for more than 75 percent of the _____ harvested in the United States.

16. _____ are fundamental life support processes upon which all organisms depend. [two words]

17. _____ is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.

18. One reason that estuaries are so productive is that the water filtering through them brings in _____ from the surrounding watershed.

19. The entire land area that drains into a particular body of water, like a lake, river or estuary is called a drainage basin or _____.

20. Estuaries are some of the most fertile ecosystems on earth, yet they may also be one of the most _____.

21. Estuaries and their surrounding wetlands act as _____ that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.

22. The _____ determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]

23. _____ estuaries are formed when rising sea levels flood existing river valleys. [two words]

24. _____ estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]

25. _____ beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.

26. A _____ is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.

27. _____ estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other.

28. _____ are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.

29. Most coastal plain estuaries in North America were formed at the end of the last_____. [two words]

30. A protected area of calm water between the coast and a barrier island is called a _____.

31. Bar-built estuaries and deltas both have large deposits of _____.

32. The first stage in the formation of a tectonic estuary typically occurs during _____.

33. _____ tend to have a moderately high input of freshwater, but very little inflow of seawater.

34. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes _____ (low oxygen) water to build up on the bottom of the estuary.

35. Estuaries with a sill are found in areas that were once covered with _____.

36. _____ create saltwater currents that move seawater into estuaries. [two words]

37. The daily mixing of freshwater and saltwater in estuaries leads to variable and dynamic chemical conditions, especially _____.

38. Because freshwater flowing into the estuary is less _____ ____ than water from the ocean, it often floats on top of the heavier seawater.

39. The difference between the average low tide and the average high tide is the _____. [two words]

40. _____ are areas in water that have equal salt concentrations.

41. The shape of the isohalines indicates the amount of _____ that is occurring, and may provide clues about the estuary's geology.

42. _____ estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]

43. In _____ estuaries, saltwater and freshwater mix at all depths. [two words]

44. A _____ estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]

45. Freshwater estuaries are driven by _____.

46. Salt marshes are a mosaic of snaking channels called _____.

47. Salt _____ are shallow depressions that contain very high concentrations of salt.

48. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of _____.

49. Salt marshes are covered with salt-tolerant plants called _____.

50. _____ is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]

51. _____ trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.

52. Many mangals can be recognized by their dense tangle of _____ that make the trees appear to be standing on stilts above the water. [two words]

53. The _____ colonizes the seaward side of mangals. [two words]

54. The zones where white mangrove and buttonwood trees grow are almost never _____.

55. Plants and animals living in estuaries must be able to respond quickly to drastic changes in _____.

56. Plants and animals that can tolerate only slight changes in salinity are called _____.

57. Plants and animals that can tolerate a wide range of salinities are called _____.

58. It requires a lot of _____ to adapt to constantly changing salinities.

59. Many species of mangrove trees have aerial roots called _____ that take up oxygen from the air for the roots.

60. Mangrove seeds that begin growing while still attached to the parent plant are called _____.

61. During low tides, oysters close up their shells, stop feeding, and switch to _____ respiration.

62. Blue crab larvae called _____ require water with a salinity over 30 ppt for optimal development.

63. As they develop, blue crabs eventually return to the estuary as young crabs called _____.

64. _____ disturbances are caused by humans.

65. Large _____ are especially destructive to estuaries.

66. A common natural disturbance to estuaries in non-tropical regions is _____. [two words]

67. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, is called _____.

68. The greatest human-caused threat to estuaries is their large-scale _____.

69. _____ is probably the most important threat to water quality in estuaries.

70. _____ is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.

71. Some toxic substances become attached to _____ that flow down rivers and get deposited in estuaries.

72. _____ is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

73. _____ pollution is the single largest pollution problem affecting coastal waters of the United States.

74. _____ are disease-causing organisms.

75. In most estuaries, the largest contributor of bacteria and viruses is probably _____. [three words]

76. _____ are plants and animals that have found their way into areas outside their normal range.

77. Non-native species are often introduced to estuaries in the _____ water of ships.

78. _____ is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.

79. The health of every National Estuary Reserve is continuously monitored by the _____.

80. As water temperature increases, the amount of oxygen that can dissolve in the water _____.

81. In estuaries, salinity levels are generally _____ near the mouth of a river where the ocean water enters.

82. The amount of oxygen that can dissolve in water _____ as salinity decreases.

83. The amount of _____ in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]

84. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and _____.

85. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down _____. [two words]

86. _____ is related to the amount of sediment and other solids suspended in water.

87. The chemical components in seawater resist large changes to _____.

88. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring _____.

## ESTUARY SELF TEST
# Word Bank

WORD BANK

stenohaline
euryhaline
energy
pneumatophores
propagules
anaerobic
zoea
megalope
anthropogenic
storms
winter ice
anoxic
glaciers
high tides
bar built
barrier
delta
tectonic
smaller
unique
geology
estuary
brackish
estuaries
salinity
variable
tides
two
freshwater
nurseries
pollutants
habitat
fish
ecosystem services
ice age
decreases
lagoons
sediment
earthquakes
fjords
tidal creeks
pannes
mudflats
nutrients
watershed
SWMP
polluted
buffers
coastal elevation
coastal plain
halophytes
smooth cordgrass
mangrove
prop roots
salinity
dense
tidal range
isohalines
highest
mixing
salt wedge
slightly stratified
vertically-mixed
storms
peat
red mangrove
flooded
salinity
wrack
conversion
pollution
biomagnification
sediments
eutrophication
nutrient
pathogens
combined sewage overflows
invasives
NERRS
increases
dissolved oxygen
photosynthesis
organic matter
turbidity
pH
chlorophyll

ESTUARY SELF TEST

# Crossword No. 1 Answer Key

## Across

4. A **vertically mixed** estuary occurs when river flow is low and tidally generated currents are moderate to strong. [two words]
7. Estuaries and their surrounding wetlands act as **buffers** that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
9. Estuaries with a sill are found in areas that were once covered with **glaciers.**
13. **Salt wedge** estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
14. Estuaries filter out **pollutants** from rivers and streams before they flow into the oceans
15. One reason that estuaries are so productive is that the water filtering through them brings in **nutrients** from the surrounding watershed.
17. **Tectonic** estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
19. **Tides** are a major influence on many estuaries.
22. Estuaries formed by rivers or streams entering massive lakes are called **freshwater** estuaries.
23. A **delta** is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
26. An **estuary** is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
27. **Isohalines** are areas in water that have equal salt concentrations.
30. **Coastal plain** estuaries are formed when rising sea levels flood existing river valleys. [two words]
31. **Barrier** beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
32. **Bar built** estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
33. In the ocean the concentration of salts, or **salinity** averages about 35 parts per thousand

## Down

1. **Ecosystem services** are fundamental life support processes upon which all organisms depend. [two words]
2. Estuaries are often called **nurseries** of the sea.
3. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their **geology**.
5. Because freshwater flowing into the estuary is less **dense** than water from the ocean, it often floats on top of the heavier seawater.
6. Tides at broad mudflats might appear to be **smaller** than tides at the end of a long, narrow inlet.
8. The first stage in the formation of a tectonic estuary typically occurs during **earthquakes**.
10. The **coastal elevation** determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
11. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes **anoxic** (low oxygen) water to build up on the bottom of the estuary.
12. The shape of the isohalines indicates the amount of **mixing** that is occurring, and may provide clues about the estuary's geology.
16. Estuaries provide habitat for more than 75 percent of the **fish** harvested in the United States.
17. Salt marshes are a mosaic of snaking channels called **tidal creeks**. [two words]
18. Most coastal plain estuaries in North America were formed at the end of the last **ice age**.[two words]
20. **Peat** is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
21. Salt **pannes** are shallow depressions that contain very high concentrations of salt.
22. **Fjords** are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
24. Of the 32 largest cities in the world, 22 are located on **estuaries**.
25. A protected area of calm water between the coast and a barrier island is called a **lagoon**.

28. Estuaries provide critical **habitat** for many birds, fish, amphibians, insects, and other wildlife.
29. Waters whose salt content is between that of freshwater and that of seawater are called **brackish**.

# Crossword No. 2 Answer Key

## Across

2. Plants and animals that can tolerate a wide range of salinities are called **euryhaline**.
3. Salt marshes are covered with salt-tolerant plants called **halophytes**.
7. In estuaries, salinity levels are generally **highest** near the mouth of a river where the ocean water enters.
9. **Turbidity** is related to the amount of sediment and other solids suspended in water.
11. During low tides, oysters close up their shells, stop feeding, and switch to **anaerobic** respiration.
13. As water temperature increases, the amount of oxygen that can dissolve in the water **decreases**.
17. As they develop, blue crabs eventually return to the estuary as young crabs called **megalope**.
19. **Mangrove** trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
20. Plants and animals that can tolerate only slight changes in salinity are called **stenohaline**.
21. **NERRS** is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
22. Scientists can determine the density of phytoplankton and the amount of primary productivity by measuring **chlorophyll**.
24. **Smooth cordgrass** is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
25. The amount of **dissolved oxygen** in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
27. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and **photosynthesis**.

28. Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down **organic matter.** [two words]
29. The amount of oxygen that can dissolve in water **increases** as salinity decreases.
30. The chemical components in seawater resist large changes to **pH.**
31. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of **mudflats.**
32. **Biomagnification** is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
33. The **red mangrove** colonizes the seaward side of mangals. [two words]
34. Many species of mangrove trees have aerial roots called **pneumatophores** that take up oxygen from the air for the roots.
35. The zone where white mangrove and buttonwood trees grow is almost never **flooded.**

## Down

1. Non-native species are often introduced to estuaries in the **ballast** water of ships.
4. Some toxic substances become attached to **sediments** that flow down rivers and get deposited in estuaries.
5. Many mangals can be recognized by their dense tangle of **prop roots** that make the trees appear to be standing on stilts above the water. [two words]
6. A common natural disturbance to estuaries in non-tropical regions is **winter ice.**[two words]
8. **Pathogens** are disease-causing organisms.
10. **Invasives** are plants and animals that have found their way into areas outside their normal range.
12. **Nutrient** pollution is the single largest pollution problem effecting coastal waters of the United States.
14. In most estuaries, the largest contributor of bacteria and viruses is probably **combined sewage overflows.** [three words]
15. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called **wrack.**

16. Mangrove seeds that begin growing while still attached to the parent plant are called **propagules**.
18. It requires a lot of **energy** to adapt to constantly changing salinities.
20. The health of every National Estuary Reserve is continuously monitored by the **SWMP**.
23. Blue crab larvae called **zoea** require water with a salinity over 30 ppt for optimal development.
26. **Eutrophication** is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.

ESTUARY SELF TEST

# Fill-in-the-Blank Answer Key

1. An **estuary** is a partially enclosed body of water and its adjacent habitats where saltwater from the ocean mixes with freshwater from rivers or streams.
2. Waters whose salt content is between that of freshwater and that of seawater are called **brackish**.
3. Of the 32 largest cities in the world, 22 are located on **estuaries**.
4. In the ocean the concentration of salts, or **salinity** averages about 35 parts per thousand.
5. The salinity of estuarine water is **variable** from one day to the next.
6. **Tides** are a major influence on many estuaries.
7. Most areas of the earth experience **two** high and low tides each day.
8. Tides at broad mudflats might appear to be **smaller** than tides at the end of a long, narrow inlet.
9. Every estuary is **unique**.
10. Estuaries are typically classified based on how saltwater and freshwater mix in the estuary and on their **geology**.
11. Estuaries formed by rivers or streams entering massive lakes are called **freshwater** estuaries.
12. Estuaries are often called **nurseries** of the sea.
13. Estuaries filter out **pollutants** from rivers and streams before they flow into the oceans.
14. Estuaries provide critical **habitat** for many birds, fish, amphibians, insects, and other wildlife.
15. Estuaries provide habitat for more than 75 percent of the **fish** harvested in the United States.
16. **Ecosystem services** are fundamental life support processes upon which all organisms depend. [two words]
17. **Peat** is a spongy matrix of live roots, decomposing organic material, and soil that helps filter pollutants out of the water.
18. One reason that estuaries are so productive is that the water filtering through them brings in **nutrients** from the surrounding watershed.

19. The entire land area that drains into a particular body of water, like a lake, river or estuary is called a drainage basin or **watershed**.
20. Estuaries are some of the most fertile ecosystems on earth, yet they may also be one of the most **polluted**.
21. Estuaries and their surrounding wetlands act as **buffers** that stabilize shorelines and protect coastal areas from floods, storm surges, and excessive erosion.
22. The **coastal elevation** determines the rate of freshwater that flows into an estuary from rivers and streams. [two words]
23. **Coastal plain** estuaries are formed when rising sea levels flood existing river valleys. [two words]
24. **Bar built** estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. [two words]
25. **Barrier** beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.
26. A **delta** is characterized by large flat fan-shaped deposits of sediment at the mouth of a river.
27. **Tectonic** estuaries are formed when the earth's tectonic plates run into or fold-up underneath each other
28. **Fjords** are steep-walled river valleys created by advancing glaciers that later became flooded with seawater as the glaciers retreated.
29. Most coastal plain estuaries in North America were formed at the end of the last **ice age**.[two words]
30. A protected area of calm water between the coast and a barrier island is called a **lagoon**.
31. Bar-built estuaries and deltas both have large deposits of **sediment**.
32. The first stage in the formation of a tectonic estuary typically occurs during **earthquakes**.
33. **Fjords** tend to have a moderately high input of freshwater, but very little inflow of seawater.
34. When a sill prevents deep waters in an estuary from mixing with deep waters of the sea, poor water exchange causes **anoxic** (low oxygen) water to build up on the bottom of the estuary.
35. Estuaries with a sill are found in areas that were once covered with **glaciers**.

36. **High tides** create saltwater currents that move seawater into estuaries. [two words]
37. The daily mixing of freshwater and saltwater in estuaries leads to variable and dynamic chemical conditions, especially **salinity**.
38. Because freshwater flowing into the estuary is less **dense** than water from the ocean, it often floats on top of the heavier seawater.
39. The difference between the average low tide and the average high tide is the **tidal range.** [two words]
40. **Isohalines** are areas in water that have equal salt concentrations.
41. The shape of the isohalines indicates the amount of **mixing** that is occurring, and may provide clues about the estuary's geology.
42. **Salt wedge** estuaries occur when a rapidly-flowing river discharges into the ocean where tidal currents are weak. [two words]
43. In **slightly stratified** estuaries, saltwater and freshwater mix at all depths. [two words]
44. A **vertically mixed** estuary occurs when river flow is low and tidally generated currents are moderate to strong.
45. Freshwater estuaries are driven by **storms.**
46. Salt marshes are a mosaic of snaking channels called **tidal creeks.**
47. Salt **pannes** are shallow depressions that contain very high concentrations of salt.
48. Burrowing organisms such as clams, mussels, oysters, fiddler crabs, sand shrimp, and blood worms are typical of **mudflats.**
49. Salt marshes are covered with salt-tolerant plants called **halophytes.**
50. **Smooth cordgrass** is one of the main components of peat and dominates the low marsh all the way up to the estuary's edge. [two words]
51. **Mangrove** trees grow at tropical and subtropical latitudes, and can grow in anoxic soils where slow moving waters allow fine sediments to accumulate.
52. Many mangals can be recognized by their dense tangle of **prop roots** that make the trees appear to be standing on stilts above the water. [two words]

53. The **red mangrove** colonizes the seaward side of mangals. [two words]
54. The zone where white mangrove and buttonwood trees grow are almost never **flooded**.
55. Plants and animals living in estuaries must be able to respond quickly to drastic changes in **salinity**.
56. Plants and animals that can tolerate only slight changes in salinity are called **stenohaline**.
57. Plants and animals that can tolerate a wide range of salinities are called **euryhaline**.
58. It requires a lot of **energy** to adapt to constantly changing salinities.
59. Many species of mangrove trees have aerial roots called **pneumatophores** that take up oxygen from the air for the roots.
60. Mangrove seeds that begin growing while still attached to the parent plant are called **propagules**.
61. During low tides, oysters close up their shells, stop feeding, and switch to **anaerobic** respiration.
62. Blue crab larvae called **zoea** require water with a salinity over 30 ppt for optimal development.
63. As they develop, blue crabs eventually return to the estuary as young crabs called **megalope**.
64. **Anthropogenic** disturbances are caused by humans.
65. Large **storms** are especially destructive to estuaries
66. A common natural disturbance to estuaries in non-tropical regions is **winter ice**. [two words]
67. A natural disturbance in salt marshes caused by the burial of vegetation by rafts of dead floating plant material, called **wrack**.
68. The greatest human-caused threat to estuaries is their large-scale **conversion**.
69. Pollution is probably the most important threat to water quality in estuaries.
70. **Biomagnification** is a process through which toxic substances can accumulate in the tissues of organisms that consume these substances.
71. Some toxic substances become attached to **sediments** that flow down rivers and get deposited in estuaries.

72. **Eutrophication** is a type of pollution in which excess nutrients stimulate an explosive growth of algae which depletes the water of oxygen when the algae die and are eaten by bacteria.
73. **Nutrient** pollution is the single largest pollution problem effecting coastal waters of the United States.
74. **Pathogens** are disease-causing organisms.
75. In most estuaries, the largest contributor of bacteria and viruses is probably **combined sewage overflows.** [three words]
76. **Invasives** are plants and animals that have found their way into areas outside their normal range.
77. Non-native species are often introduced to estuaries in the **ballast** water of ships.
78. **NERRS** is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water.
79. The health of every National Estuary Reserve is continuously monitored by the **SWMP.**
80. As water temperature increases, the amount of oxygen that can dissolve in the water **decreases.**
81. In estuaries, salinity levels are generally **higher** near the mouth of a river where the ocean water enters.
82. The amount of oxygen that can dissolve in water **increases** as salinity decreases.
83. The amount of **dissolved oxygen** in an estuary's waters is the major factor that determines the type and abundance of organisms that can live there. [two words]
84. Oxygen enters the water through two natural processes: diffusion from the atmosphere, and **photosynthesis.**
85. Bacteria, fungi, and other decomposer organisms reduce DO (dissolved oxygen) levels in estuaries because they consume oxygen while breaking down **organic matter** [two words]
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